Optimization Modeling of Phosphorus Removal in Reservoir and Stormwater Treatment Areas

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The Lake Okeechobee Watershed Project (LOWP) is a major component of the Comprehensive Everglades Restoration Program (CERP). A primary goal of the LOWP is to reduce phosphorus loadings to Lake Okeechobee from contributing watershed planning areas north of the lake (Figure 1).

Phosphorus must be reduced to restore lake water quality and to meet the Total Maximum Daily Load (TMDL) of 105 metric tons per year (MTY). Best Management Practices that are already planned will reduce phosphorus loading from 433 to 235 MTY. The LOWP goal is to provide the additional 130 MTY needed to meet the TMDL (Table 1).

The second LOWP goal is to provide surface water storage to help manage ecologically desirable lake levels and reduce the need for damaging flood discharges from Lake Okeechobee to estuarine areas on the east and west coasts. The reservoirs will also provide a continuous supply of water to the constructed wetlands (Stormwater Treatment Areas).

Planning Area	Total P Loading (Annual Average Mton/year)		
	Future (with BMPs)	Target LOWP Reduction	Future with LOWP
Lake Istokpoga/ Indian Prairie	70.1	60.0	10.1
Fisheating Creek	60.5	50.0	10.5
Kissimmee River	55.4	0	55.4
Taylor Creek / Nubbin Slough	49.0	20.0	29.0
TOTAL	235	130	105

Table 1: Average Annual Phosphorus Loading from Planning Areas to Lake Okeechobee.

Goal	Approach	Management Measure
Reduce Phosphorus Loading to Lake Okeechobee	Capture runoff and treat prior to discharge to the lake	Stormwater Treatment Areas
Provide improved management of lake levels	Capture and detain peak flows to lake	Above ground reservoirs
Reduce freshwater release to estuaries	Capture and detain peak flows to lake; improved lake management	Above ground reservoirs

Table 2: LOWP Project Components.

A combination of above-ground reservoirs and Stormwater Treatment Areas (STAs) will be used to capture and treat runoff (Table 2). Configuration options are:

- Stand-alone (off-line) reservoirs that withdraw from a stream or canal and discharge to the same or a different stream or canal.
- Stand-alone (off-line) STAs that are similarly configured, and reservoirs that withdraw from a stream or canal and discharge to an STA, which then discharges to a stream or canal.

A directly coupled reservoir/STA system is called a Reservoir Assisted Stormwater Treatment Area (RASTA). For each of four basins (or Planning Areas), five Planning Area Alternatives (PAAs) were developed, consisting of combinations of off-line reservoirs, off-line STAs, and RASTAs (HDR Engineering, Inc., 2005). Within each Planning Area, existing land uses and ecological values were used to pre-select land areas that could be used for construction of reservoirs and STAs.

The number or reservoir and STA combinations in a Planning Area was potentially quite large. The Lake Okeechobee Combinatorial Watershed Analysis Program (LOWCAP) was developed and utilized to evaluate the large number of possible combinations. LOWCAP computed storage volumes and phosphorus load reductions, estimated costs, and sorted alternatives based on average annual values.

Results were used to identify a set of 20 cost-effective PAAs that met the project goals. The next step was to perform more detailed evaluations of the PAAs to verify storage capacities of reservoirs and phosphorus load reduction capacities and to develop appropriate capacities for pump stations, structures, and canals.

Modeling Approach

Modeling tools were needed to design reservoir and STA systems that could achieve project objectives within available land area constraints. Two coupled models were used to simulate system performance: a reservoir model (RESOPT 3.0) and an STA simulation model. A stream matrix model was also employed to connect reservoirs and STAs within the stream and canal network.

Simulation modeling was applied over a 36-year period of record to assess the effect of superimposing reservoirs and STAs (i.e, the LOWP) onto project Planning Areas. The without-project conditions were the projected future flows and loadings after implementation of planned BMPs, which were derived from previous extensive modeling of the watersheds (Soil and Water Engineering Technology, Inc., 2004).

RESOPT 3.0 is a water budget and phosphorus mass balance model that was developed specifically to simulate LOWP reservoirs. Phosphorus flux components in RESOPT 3.0 are illustrated in Figure 2, and water budget components are similar. Salient features of RESOPT 3.0 are:

- Reservoir water column control volume
- Completely mixed water column (0-D)
- One-day timestep
- Flow balance for reservoir
- Total phosphorus mass balance
- Total phosphorus (no speciation)
- Stream diversion rules
- Reservoir release rules

For a given reservoir location, the point of withdrawal from stream to reservoir and the point of reservoir discharge were specified, as were capacity of withdrawal pumps. Stream flow and phosphorus concentration time series at the point of withdrawal were used to calculate the daily volume and phosphorus mass routed into the reservoir for the specified withdrawal pump capacity. Precipitation time series were assembled from monitoring stations within each basin, and potential evaporation calculations produced sinusoidally varying evaporation rates.

Reservoir modeling included an over-

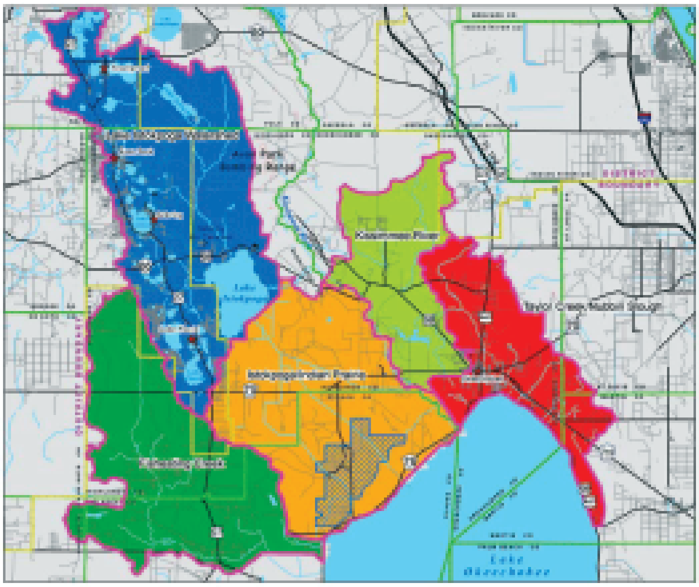

Figure 1: Lake Okeechobee Watershed Planning Areas.

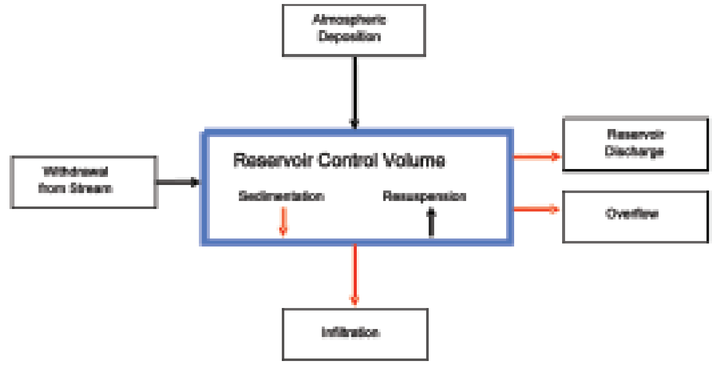

Figure 2: Mass balance flux components for Total Phosphorus in RESOPT 3.0.

flow feature for high-precipitation events imposed on full or near-full reservoirs; excess water and phosphorus greater than maximum working depth (8.0 ft. for all LOWP reservoirs) were routed to a receiving stream or canal via a crest overflow. Phosphorus mass balance modeling (**Figure 2**) included sedimentation and resuspension.

Phosphorus sedimentation was modeled using a constant settling velocity, with the parameterization resulting in a first-order, depth-dependent removal rate constant (Smith, et al, 2004). Phosphorus resuspension was estimated using the Shallow Water Wave Model (U.S. Army Coastal Engineering Laboratory, 2002), a quadratic relationship for bottom shear stress (Lijklema et al., 1994), and resuspension rate as a linear function of bottom shear stress (Sheng and Lick, 1979).

Average daily wind velocity was the driving force in the resuspension calculation. Generally, depths of less than 1.5 feet and wind velocities of greater than 15 miles per hour were needed to discern a noticeable resuspension effect. Daily direct phosphorus deposition onto the reservoir surface was predicted using a rainwater phosphorus concentration that was estimated from the average areal total deposition rates over the Lake Okeechobee watershed.

DMSTA, the Dynamic Model for Stormwater Treatment Areas, is a non-steady-state model of Stormwater Treatment Areas that simulates the hydrologic water balance and phosphorus removal processes in treatment wetlands (Walker and Kadlec, 2004). The basic function of DMSTA is to predict phosphorus removal efficiency of an STA. For a given STA area, STA cell configuration (number of parallel trains, number of cells in series), cell aspect ratios, and given influent flowrate and total phosphorus concentration time series, DMSTA predicts the flowrate and total phosphorus concentration in STA effluent.

The DMSTA-predicted treatment efficiency of the STA is calculated by the differences between influent and effluent phosphorus mass on a cumulative basis over a selected averaging period. DMSTA was applied to LOWP STAs using the biokinetic parameters for emergent macrophyte wetlands, which was the STA vegetation assemblage specified by the Project Delivery Team.

Operating Rules

Operating rules were needed to simulate the performance of reservoirs and STAs. These included specifying rules for the rates of withdrawal from canals to reservoirs, release rates from reser-

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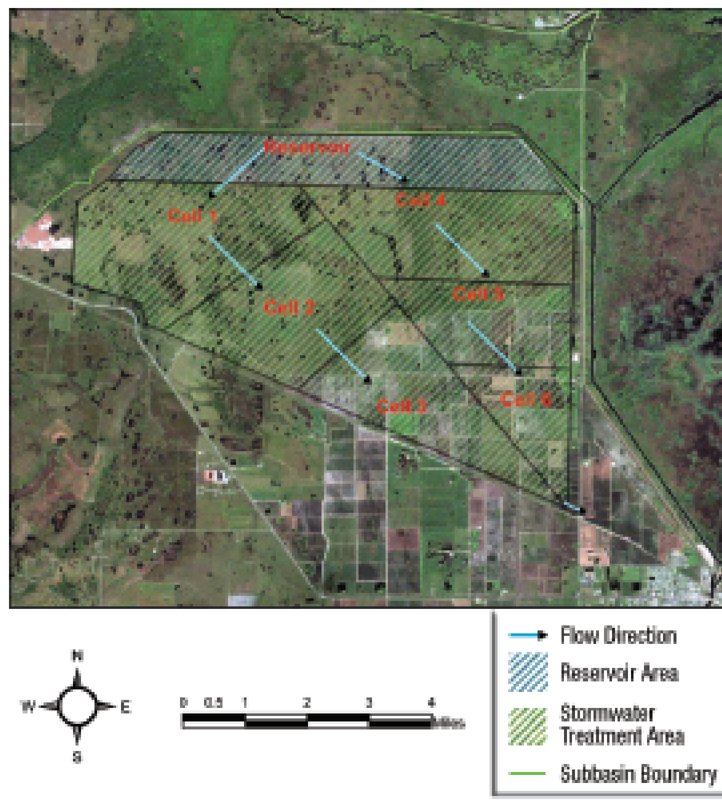

Figure 3: Fisheating Creek RASTA: 3240 acre reservoir and 6-cell STA (17,000 acre).

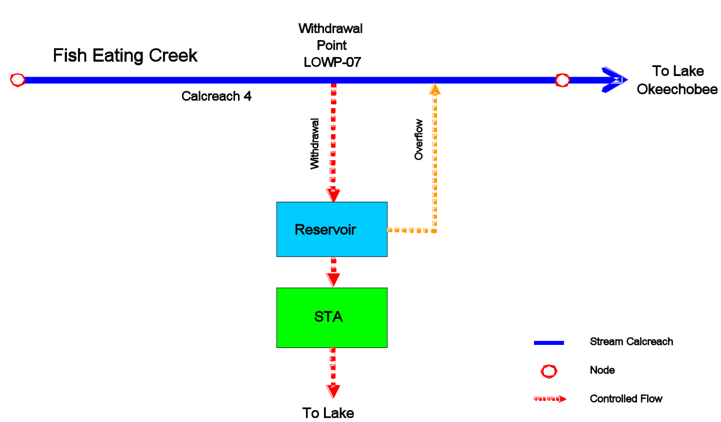

Figure 4: Fisheating Creek matrix.

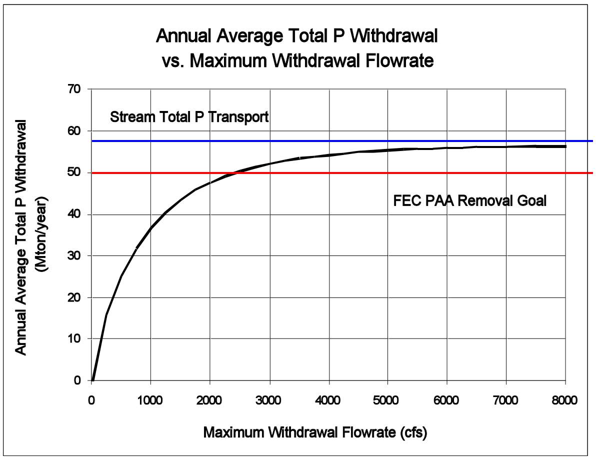

Figure 5: Phosphorus withdrawal from Fisheating Creek versus pump capacity.

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voirs, minimum reservoir depths, hydraulic loading rates to STAs, and minimum flows to STAs to prevent dryout.

Central to the complexity of the system were high daily variations in flowrates, along with the accompanying variation in phosphorus loading. Also, hydrology in the Okeechobee basins is highly seasonal, and dry-season dynamics can be quite different than wet-season dynamics. The project delivery team ultimately adopted a simplified series of operating rules commensurate with the current level of planning effort.

Operating rules were applied at the beginning of each one-day timestep. The maximum withdrawal rate from stream or canal to reservoir was established based on the cumulative distribution of streamflow at the point of withdrawal. For any given day, the maximum withdrawal rate was equal to the lesser of two quantities: approximately the 95th percentile stream flow (95 percent of flows less than or equal to), or the actual daily streamflow, with the 15th percentile streamflow (low streamflow) subtracted from each to maintain a minimum instream flow.

An analysis of streamflow rates was performed to identify an efficient inflow pump capacity. Typically, this capacity was approximately the 95th percentile stream flow. For a stand-alone reservoir, release rate was based on analysis of mass phosphorus removal within the reservoir, and also mass phosphorus removal in a downstream STA, if it existed.

In order to prevent reservoir dryout, reservoir depth/release rules were formulated. Initially, rules were developed that decreased allowable release rates in a stepwise pattern as reservoir depth decreased.

The project delivery team decided to use a minimum depth of one foot with a simple switching function. At depths greater than one foot, reservoir release was based on optimizing performance of the downstream STA. At depths of one foot or less, reservoir release rate was limited to offset ET in the downstream STA.

For STAs, the areal hydraulic loading rate (HLR) is an important design and operating parameter. HLR is the applied flowrate per surface area (L3/L2T). Simulation studies using steady-state flowrates and loadings indicated an optimum STA HLR of approximately 6 cm/day (Keller and Knight, (2004) to maximize phosphorus mass reduction.

Initially, flowrates to LOWP STAs were calculated using a 6 cm/day HLR. It soon became apparent that that the steady-state analysis results had a limited utility for the LOWP STAs that operated under highly variable flowrates.

An alternative modeling approach was taken. A maximum HLR of 20 cm/day was specified; STA influent flowrates were maintained at the maximum HLR whenever possible.

Since the maximum HLR could be met only a small fraction of the time, the resulting average HLR was much lower, and always less than 5 cm/day. Furthermore, water levels in STAs were never at excessively high levels that could damage vegetation for continuous periods.

Based on this analysis, reservoir release rates to directly coupled STAs, and maximum pump sizes STAs directly receiving stream or canal withdrawals, were based on the STA area and 20 cm/day HLR. For a RASTA, the STA would receive limited inflow if the reservoir depth was less than or equal to 1.0 foot.

Design Examples

Five alternative configurations of reservoirs, STAs, and/or RASTAs were evaluated for each of four Planning Areas. A summary of one alternative from two Planning Areas is presented in this article.

The initial example, the first alternative for Fisheating Creek (FEC-01), is a relatively simple configuration. The second design, alternative 2 for the Lake Istokpoga/Indian Prairie basin (ISTOK-02), is much more complicated. These two PAAs will reduce phosphorus loading to Lake Okeechobee by 110 MTY, which is 85 percent of LOWP target reduction.

Fisheating Creek Planning Area

Fisheating Creek enters Lake Okeechobee from the northwest and transports 60.5 MTY into the lake for the future without project condition (Table 1). The LOWP target phosphorus reduction for the Fisheating Creek Planning Area was 50 MTY.

Prior planning studies had identified a number of land areas in the watershed as potential sites for reservoirs and STAs. Due to concerns for the ecological and recreational

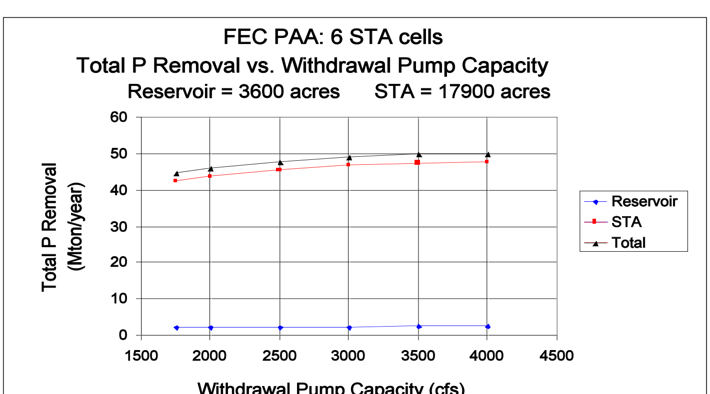

Figure 6: Phosphorus fluxes through RASTA treatment system at FEC.

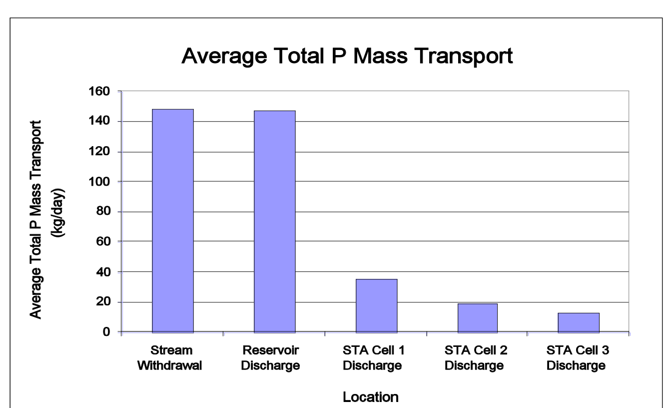

Figure 7: Phosphorus fluxes through RASTA treatment system at FEC.

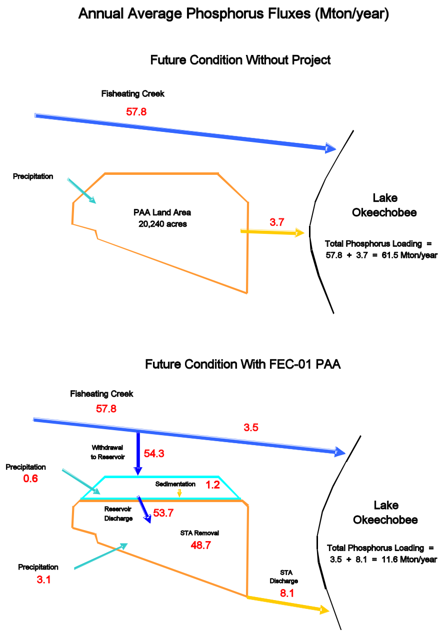

Figure 8: Effect of FEC-01 on phosphorus fluxes.

values of Fisheating Creek, it was decided to use sites near the downstream end of the creek.

The final available land area was located less than a mile from Lake Okeechobee, near the downstream end of the creek. The FEC-01 alternative design consisted of a 3,240 acre reservoir directly coupled to a 17,000 acre 6-cell STA (**Figure 3**). The RASTA served as an end of pipe system for the entire Fisheating Creek watershed.

A stream matrix (**Figure 4**) was developed to represent the Fisheating Creek Planning Area. Water was withdrawn from the creek to the reservoir and STA treatment system. The STA discharges to Lake Okeechobee (or alternatively back to the last section of Fisheating Creek), and reservoir overflow is routed to the creek. The Fisheating Creek flowrate and total phosphorus concentration time series at the point of diversion was used to generate a plot of phosphorus withdrawal from the stream based on withdrawal pump capacity (**Figure 5**).

In order to capture the total phosphorus mass required for the Planning Area, it was necessary to adjust the inflow pump capacity to capture more of the peak flood flows. Total phosphorus mass withdrawn from the creek increases rapidly up to 2,000 cfs pump capacity and becomes increasingly limited for greater pump capacities. Removal of 50 metric tons per year of phosphorus (the FEC removal target) would require a pump size of 2,400 cfs or greater.

The phosphorus loading analysis shown in Figure 5 highlighted an important mini-

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Plan Area (acres)	
Reservoir	3,240
STA	17,000
Total	20,240
Withdrawal Pump Capacity (cfs)	3,500
Reservoir	
Average Storage (acre-ft.)	1550
Average Water Retention Time (days)	2.4
Flow Weighted Phosphorus Concentrations (ug/L)	
Influent	173.4
Discharge	172.6
Stormwater Treatment Area	
Hydraulic Loading Rate (cm/day)	
Maximum	20
Average	1.24
Total P Loading Rate including atmospheric deposition (kg/ha-yr)	8.26
Total P Removal Rate (kg/ha-yr)	7.08
Average Annual Total Phosphorus Removal (Mton/year)	
Reservoir	1.2
STA	48.7
Total	49.9

Table 3: FEC-01 Summary.

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mum size constraint to the withdrawal pump capacity for FEC-01. To meet the FEC phosphorus removal requirements, a large pump size is needed to capture large loadings that follow high rainfall events.

RESOPT 3.0/STA simulations were conducted to optimize the PAA system. FEC-01 simulations consisted of selection of the capacity of the pump for withdrawal from Fisheating Creek to the reservoir, specification of minimum stream flow in the creek below which no withdrawal was allowed, selecting a maximum STA hydraulic loading rate (HLR), and selecting a minimum reservoir depth below which no reservoir release would occur. The minimum stream flow was the 15th percentile low flow (9.7 cfs), maximum STA HLR was 20 cm/day, and minimum reservoir depth was 1.0 foot.

The main degree of freedom in FEC-01 modeling was selection of the maximum withdrawal pump capacity from Fisheating Creek. RESOPT 3.0 model results generated a time series of reservoir discharge and total phosphorus concentration that were used directly as input to the DMSTA model for the STA.

Simulations were conducted across a range of withdrawal pump capacities (Figure 6). A withdrawal pump capacity of 3,500 cfs was required to achieve the target annual average total phosphorus removal of 50 metric tons per year. Total phosphorus removals increased as maximum pump capacity increased and were dominated by the STA. The relatively limited reservoir removal predicted by RESOPT 3.0 was due to a short average water residence time of 2.4 days.

Average daily total phosphorus mass transport through the FEC-01 treatment system are shown in Figure 7. The average stream withdrawal of 149 kg/day (54.4 Mton/year) comprises 94 percent of Fisheating Creek transport.

Most phosphorus entering the reservoir is discharged to the STA. Phosphorus mass reduction is greatest in the STA Cell 1, followed by smaller reduction in STA Cell 2 and still smaller reduction in STA Cell 3. The decline in removal rates as the concentration successively decreases through treatment units in series is a common characteristic of biochemical treatment processes. The total phosphorus transport profile through cells in the parallel treatment trains (Cells 4, 5, and 6) is similar to that in the Cells 1, 2, and 3.

A summary of FEC-01 design and operating characteristics is shown in Table 3. The annual average storage of 1,550 acre-feet is 6 percent of the maximum storage of 25,900 acre-feet at reservoir full conditions. The relatively short reservoir water residence time of 2.4 days resulted in little difference in flow weighted total phosphorus concentrations in reservoir influent and discharge. The average HLR to the STA was 1.24 cm/day, only a small fraction of the maximum HLR.

The system design allows the treatment system to capture large flow and loading events, while average loadings are limited. The average areal phosphorus loading to the STA was 8.26 kg/ha-year, and the STA was capable of removing 86 percent of this load. The average phosphorus concentration in the effluent of the FEC 01 STA was 23.4 ug/L.

A cautionary note is that consistently achieving effluent phosphorus concentrations of less than 25 ug/L may be a challenge for the macrophyte-dominated STAs that were specified in LOWP design. In subsequent phases, the planning process must consider alternative structural or operational adjustments to the alternatives to minimize, or eliminate the need to reach such low effluent concentrations in order to meet the overall target for load reduction.

The effect of FEC-01 on phosphorus fluxes in the Fisheating Creek Planning Area is shown in Figure 8. For the future without project condition, average total phosphorus loading to Lake Okeechobee from Fisheating Creek and the land area of the FEC-01 PAA is 61.5 metric tons per year. Withdrawing water from Fisheating Creek greatly reduces loading from the creek, and the majority of the withdrawn phosphorus mass is removed in the treatment system. The FEC-01 alternative reduces net phosphorus loading to Lake Okeechobee by an average of 49.9 metric tons per year.

Lake Istokpoga/Indian Prairie Planning Area

The Lake Istokpoga/ Indian Prairie Planning Area contributes 70.1 MTY of phosphorus to the northwest area of Lake Okeechobee (Figure 1) for the future without project condition (Table 1). Phosphorus enters the lake directly through the C-41 and C-40 Canals and through the Kissimmee River through C-41A and other smaller canals (Table 4). The LOWP target phosphorus reduction for Lake Istokpoga/Indian Prairie Planning Area was 60 MTY, or 86 percent of the future without project loading.

The configuration of ISTOK-02, shown in Figure 9, utilizes the land area that was determined to be available for siting reservoirs and STAs. ISTOK-02 consists of one reservoir and three STAs with sizes indicated in Table 5. ISTOK-02 consists of a 6,480-acre offline reservoir on C-41A Canal with return of discharge back to the C-41A Canal. MM2 North STA is also located on the C-41A Canal, while MM2 South and MM3 STAs withdraw from the C-40 Canal and the C-41 Canal, respectively (Figure 9).

The task of optimizing the ISTOK 02 design and achieving the target phosphorus removal goal of 60 metric ton per year was formidable for two reasons:

First, there was a discussed discrepancy between the location of phosphorus loading within the Istokpoga Planning Area and the size of available land areas. Analysis of flows and loadings from the major canals indicated that Harney Pond (C-41) Canal accounted

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Canal	Receiving Water	Average Discharge		Average Total Phosphorus Transport	
		1000 acre-ft./year	%	Mton / year	%
Harney Pond (C-41)	Lake Okeechobee	203.2	45.2	36.3	51.8
Indian Prairie (C-40)	Lake Okeechobee	92.4	20.5	15.4	22.0
C-41A	Kissimmee River	138.2	30.7	15.2	21.7
Canals on West Side of Kissimmee River South of C-41A Canal	Kissimmee River	16.1	3.6	3.2	4.6
TOTAL		449.9	100.0	70.1	100.0

Table 4: Annual Average Volume and Phosphorus Loading to Lake Okeechobee (Future without project).

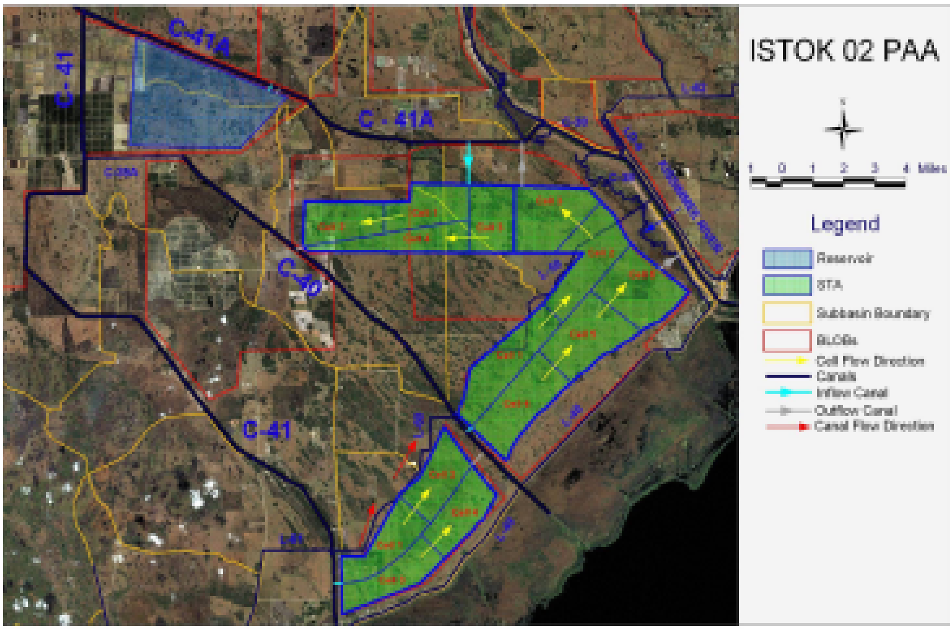

Figure 9: Configuration of ISTOK-02 Planning Area Alternative.

Average Annual Total Phosphorus Transport	Mton/year
C-41A Canal	0.4
Canals South of C-41A Canal	1.5
Indian Prairie Canal (C-40)	0.7
Harney Pond Canal (C-41)	0.0
MM2 STA North	0.0
MM2 STA South	7.9
MM3 STA	0.0

Table 7: Phosphorus loading components for ISTOK-02.

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for 51.8 percent of phosphorus loading, while Indian Prairie and C-41A Canals accounted for about 22 percent of phosphorus loading each. While phosphorus loading was highest to the south and west, the available land area directly adjacent to Harney Pond (C-41) Canal was only 7,509 acres.

The larger available land areas were located to the north and west. From an earlier analysis, it was determined that the phosphorus reduction ability of the 7,509-acre available land area adjacent to C-41 Canal was insufficient to enable ISTOK-02 to achieve the overall load reduction objective of 60.0 MTY.

The second challenge to achieving 60.0 MTY removal was phosphorus concentration. The flow weighted phosphorus concentration for the loadings from the Istokpoga/Indian Prairie Planning Area was 126 ug/L. Achieving 86-percent reduction resulted in an estimated flow weighted "effluent" concentration of 18 ug/L.

Achieving these low average phosphorus levels is a considerable challenge for reservoir/STA systems using macrophyte-dominated STAs. As with the analysis for Fisheating Creek alternatives, subsequent phases of the planning process must consider structural or operational adjustments to this plan to minimize or avoid the need to achieve these low effluent concentrations.

Management Measure	Modeled Area (acre)			
	Reservoir	STA	Total	Total MM
1	6,480	0	6,480	6,480
2 North	0	7,500	7,500	23,500
2 South	0	16,000	16,000	
3	0	7,509	7,509	7,509

Table 5: ISTOK-02 Configuration.

	MM2 North STA	MM2 South STA	MM3 STA
Maximum Hydraulic Loading Rate (cm/day)	12.1	15.1	16.1
Average Hydraulic Loading Rate (cm/day)	1.2	1.9	2.2
Average Phosphorus Loading Rate (kg/ha-year)	3.6	4.2	11.5
Average Phosphorus Loading Rate (kg/ha-year)	2.9	2.9	8.6
Average Effluent Total Phosphorus Concentration (ug/L)	14.1	15.2	35.6

Table 6: ISTOK-02 STA Operating Characteristics.

Alternative designs were conceptualized, developed, and simulated, resulting finally in the ISTOK-02 configuration shown in Figure 9. The basis for development and analysis of alternative designs was to evaluate individual system components using an approach that consisted of apportioning the 70.1 minus 60, or 10.1 metric tons per year "allowable loading" among the individual contributing components.

The contributors to the "allowable loading" were discredited into canals and management measure discharges. Canal loadings consisted of any phosphorus that was not withdrawn to a management measure or that was returned from a reservoir. Management measure contributions to the "allowable loading" consisted of management measure discharges.

Several design features were specifically developed to achieve the phosphorus removal target and are incorporated in ISTOK-02:

- MM3 was operated as a "high rate" STA to achieve high areal removal rates.
- MM3 effluent was routed to MM3 South STA for further treatment of the high effluent concentrations from MM3 STA.
- Water from Harney Pond (C-41) Canal Water to that was not withdrawn to MM3 STA was also routed to MM2 STA South.
- MM2 North STA discharge was routed to C-40 Canal, where it could be further treated in MM2 STA South.

Numerous iterative simulations were used to balance the interacting design decisions of reservoir pump size and discharge rate, size of pumps to the three STAs, and STA size. Phosphorus removal from MM1 reservoir as a function of withdrawal pump capac-

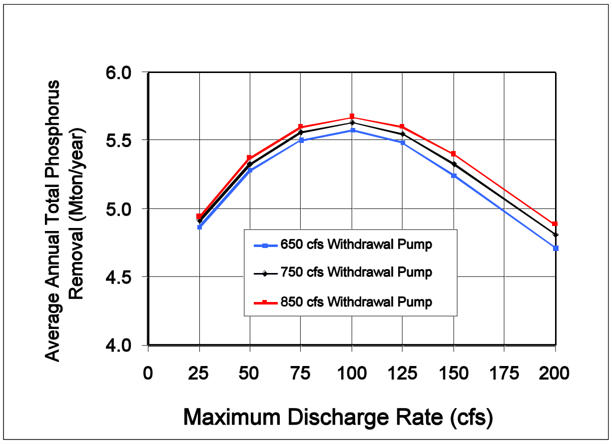

Figure 10: Effect of discharge rate on phosphorus removal in MM1 reservoir.

ity and discharge rate is shown in Figure 10. The figure indicates limited increases in annual phosphorus removal as withdrawal pump size increases from 650 to 850 cfs, but highest removal for a 100 cfs discharge rate for all withdrawal pump capacities.

The final ISTOK-02 design included a 750 cfs withdrawal pump capacity and 100 cfs discharge rate. MM2 reservoir achieved an annual average phosphorus removal of 5.6 MTY. Performance features of MM1 reservoir are shown in Figures 11 through 13. Average depths ranged from just over 1 foot to close to the 8-foot maximum working depth.

The reservoir dried out in only one year, while maximum capacity was reached at least once in 70 percent of the years. Average annual storage ranged from 7,000 to over 50,000 acre-feet and averaged 31,500 acre-feet. Average phosphorus removal ranged from less than one half to 12.3 MTY, and reflects the difference in water-column phosphorus mass from beginning of year to end.

Operating characteristics for ISTOK-02 STAs are summarized in Table 6. A total of 37,409 acres are dedicated to reservoirs and STAs. The reservoir provides an average storage of 31,500 acre-feet, and the 112-day average residence time provided 5.6 MTY phosphorus removal.

The average areal phosphorus removal rate of MM1 reservoir is 2.1 kg/ha-year, or well below the more efficient STAs. The three STAs account for over 90 percent of the phosphorus removal, but there are substantial differences in STA areal removal rates. Although less than half as large as MM2 STA South, MM3 STA removes substantially more phosphorus than MM2 South due to the higher areal removal rates that are predicted to occur with higher influent concentrations.

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Plan Area (acres)	
Reservoir	6,480
STAs	31,009
Total	37,409
Reservoir	
Average Storage (acre-ft.)	31500
Average Water Retention Time (days)	112
Flow Weighted Phosphorus Concentrations (ug/L)	
Influent	84.7
Discharge	47.9
Stormwater Treatment Areas	
Hydraulic Loading Rates (cm/day)	
Maximum	12.2 – 16.1
Average	1.2 – 2.2
Total P Loading Rates including atmospheric deposition (kg/ha-yr)	2.9 – 8.6
Total P Removal Rates (kg/ha-yr)	14.1 – 35.6
Average Annual Total Phosphorus Removal (Mton/year)	
Reservoir	5.6
STA MM2 North	8.7
STA MM2 South	19.2
STA MM3	26.1
Total	59.6
Average Annual Average Total Phosphorus Loading (Mton/year)	
Without PAA	70.1
With ISTOK-02 PAA	10.5
Reduction	59.6

Table 8: ISTOK-02 Summary.

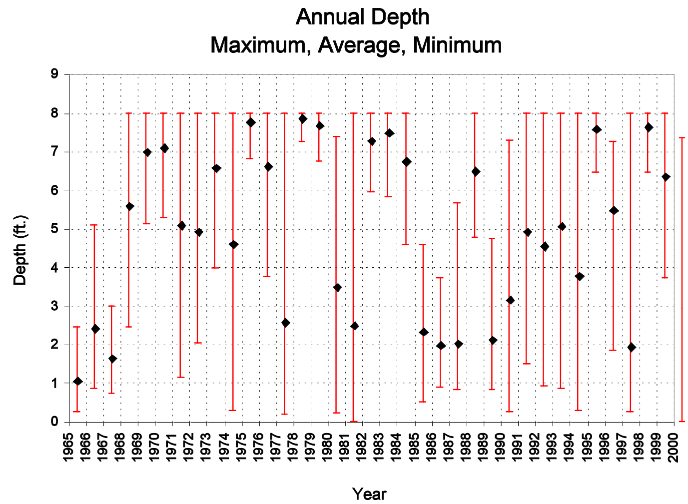

Figure 11: MM1 reservoir average depth.

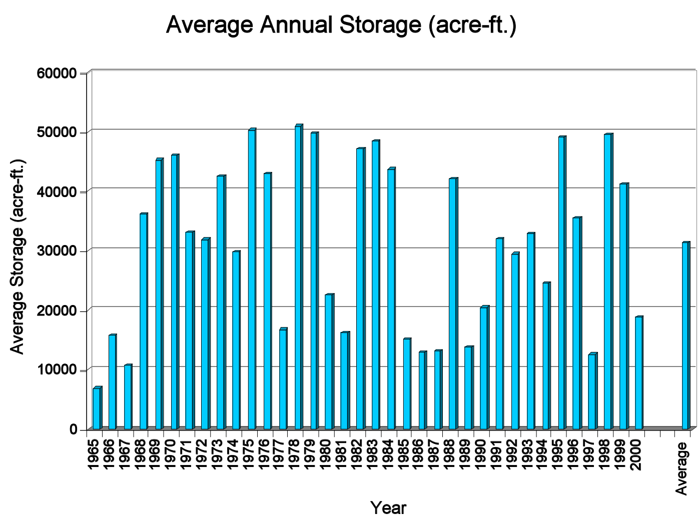

Figure 12: MM1 average reservoir storage.

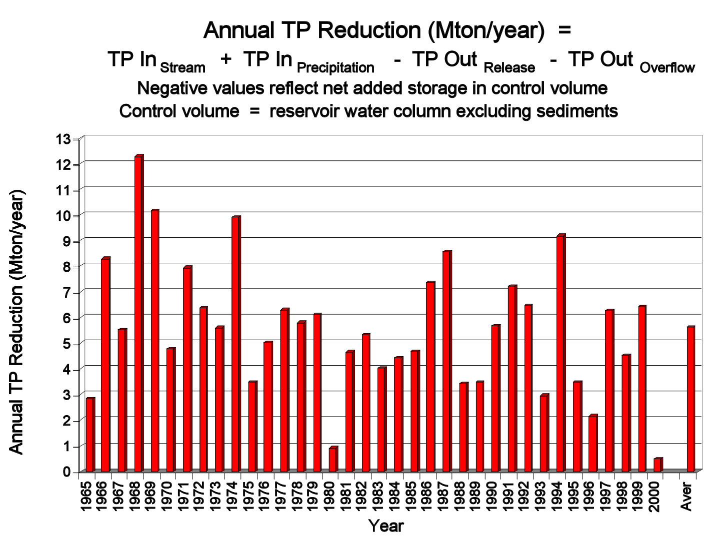

Figure 13: MM1 reservoir average phosphorus reduction.

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The average phosphorus concentrations in the effluent of the ISTOK-02 STAs were 14.2, 15.2, and 35.6 to ug/L, respectively, in MM2 STA North, MM2 STA South, and MM3 STA. MM2 STA North and MM2 STA South were in a "low loading" range, while the higher loading to MM3 STA resulted in higher effluent phosphorus concentrations.

A cautionary note is that consistently achieving effluent phosphorus concentrations of less than 25 ug/L may be a challenge for the macrophyte-dominated STAs that were specified in LOW design. Alternatives will have to be considered to address this issue in subsequent phases of the planning process.

Conclusions & Recommendations

Model simulations were extremely valuable to sizing reservoir and STA systems in the Lake Okeechobee Watershed. Simulations provided a rational basis for the locations and sizing of reservoirs, STAs, pump stations, and preliminary operations. Model simulations predicted that targeted reductions of total phosphorus into Lake Okeechobee could be met with reservoir and STA systems in both Fisheating Creek and Lake Istokpoga/Indian Prairie Planning Areas.

Several key recommendations emerged from the system modeling.

- Seasonal effects to reservoir and STA will likely be quite significant, and seasonally based operating rules should be developed.
- Areal removal rates of macrophyte dominated STAs decrease significantly as influent phosphorus concentrations decline below 50 ug/L. The result is large increases in required STA area for relatively small increases in annual mass removal.
- Alternative STA assemblages should be explored for the Lake Istokpoga/Indian Prairie Canal Planning Area, including submersed aquatic vegetation (SAV) systems, periphyton assisted STAs, and STA systems in series.
- Reservoir/STA interactions should be systematically explored through a program of modeling and field data collection.
- A comprehensive modeling framework is needed to integrate multiple reservoir/STA systems to predict and optimize overall phosphorus removal and water storage in the Lake Okeechobee Watersheds.

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